Dynamically and Thermodynamically Stratified Aerosol and Cloud Interactions

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Challenges of using satellite data to study aerosol and cloud interactions

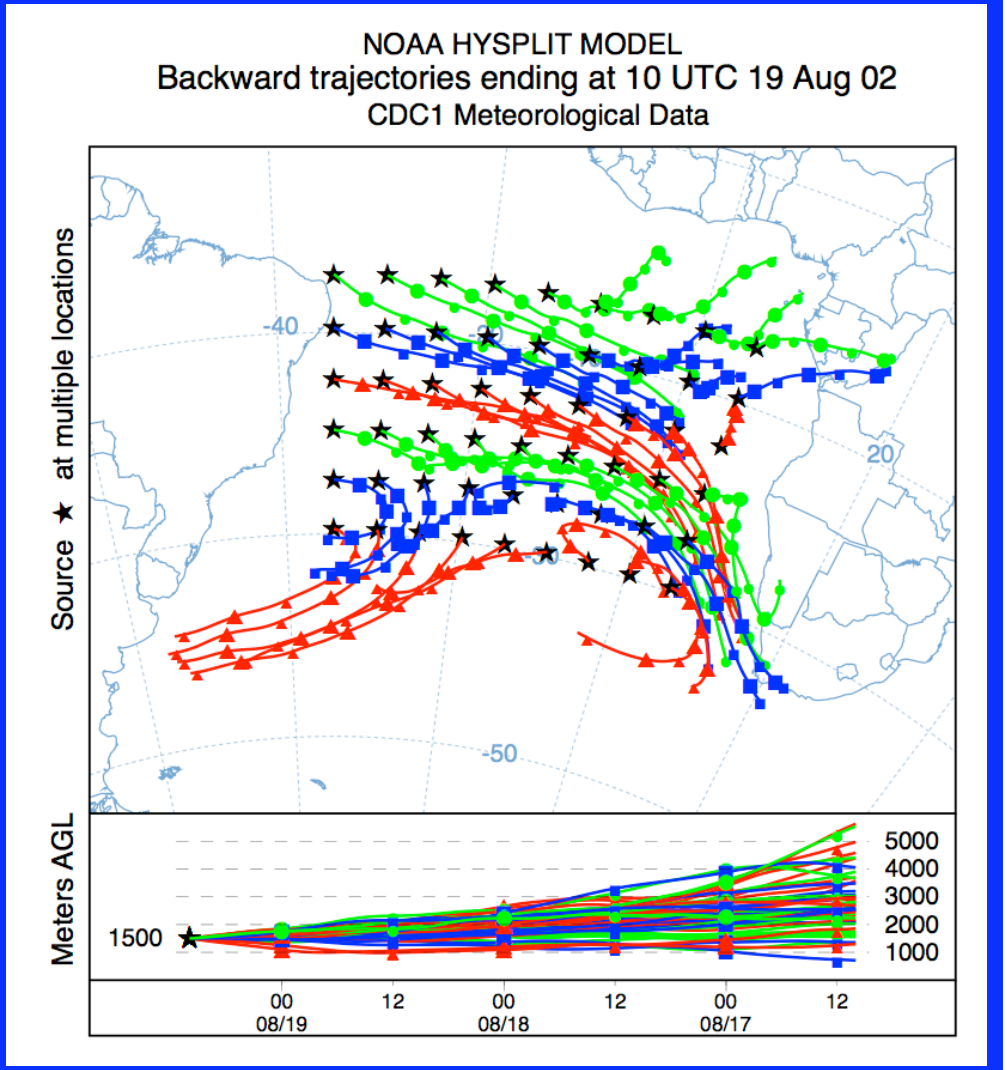
- Cloud adjacency effect:
  - AOD increases as cloud optical depth (COD) and cloud cover (Wen et al, 2006, 2007);
- Bluing of aerosols near clouds:
  - Angstrom exponent increases as COD and cloud cover (Marshak et al., 2008);
- Biases in cloud retrievals:
  - For partially cloudy pixels, threshold cloud retrievals tend to underestimate COD and overestimate cloud droplet effective radius (Re). These biases decrease as cloud cover increases (Matheson et al., 2006);
- If use AOD to sort clouds, the above mentioned artifacts will result in smaller Re, larger COD, and larger Angstrom exponent as AOD increases.

Combine satellite, back trajectory, reanalysis data to study aerosol and cloud interactions

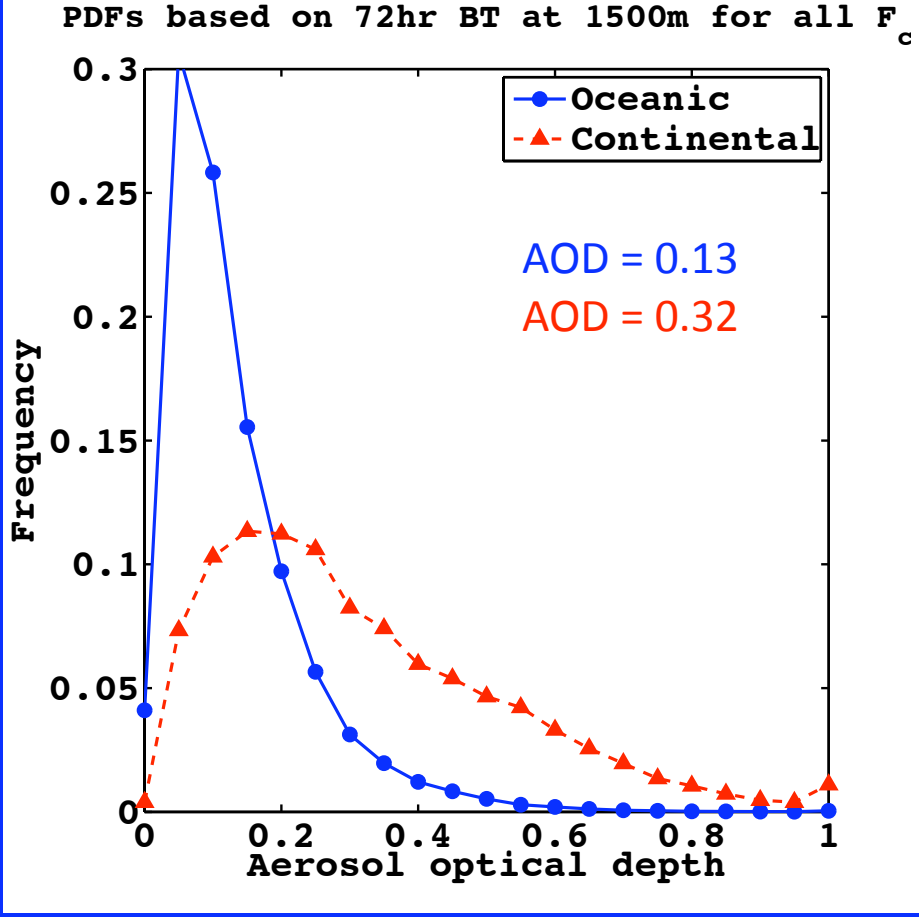
- SSF daily mean data
  - Aerosol optical depth (AOD), cloud droplet effective radius (Re), cloud optical depth, liquid water path, cloud fraction, TOA albedo
- Hysplit back trajectory analysis
  - Aerosol origin is identified as continental or oceanic
- ERA interim reanalysis
  - Estimated Inversion Strength (EIS, from Wood 2006) and vertical velocity at 700 hPa (ω_{700}) to constrain the dynamic and thermodynamic conditions;
- Results of South Atlantic (0~30°S, 35°W~10°E) during the JJA season (2001 to 2006) are presented.

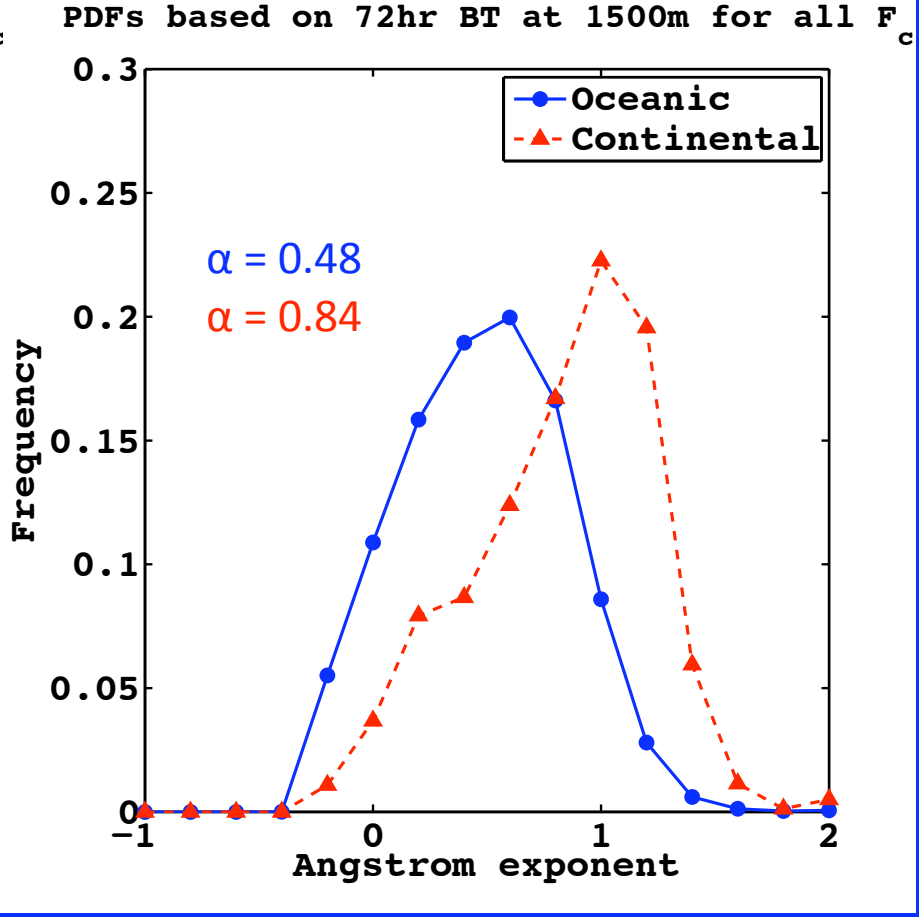
Back trajectory to determine aerosol origin

- Run Hysplit back trajectory at 1500 m for 72 hours to identify the origin of aerosols;
- If never over the continents during the past three days, the aerosols are identified as oceanic, otherwise as continental.



Aerosols with continental origin have higher optical depth and more fine mode particles than aerosols with oceanic origin

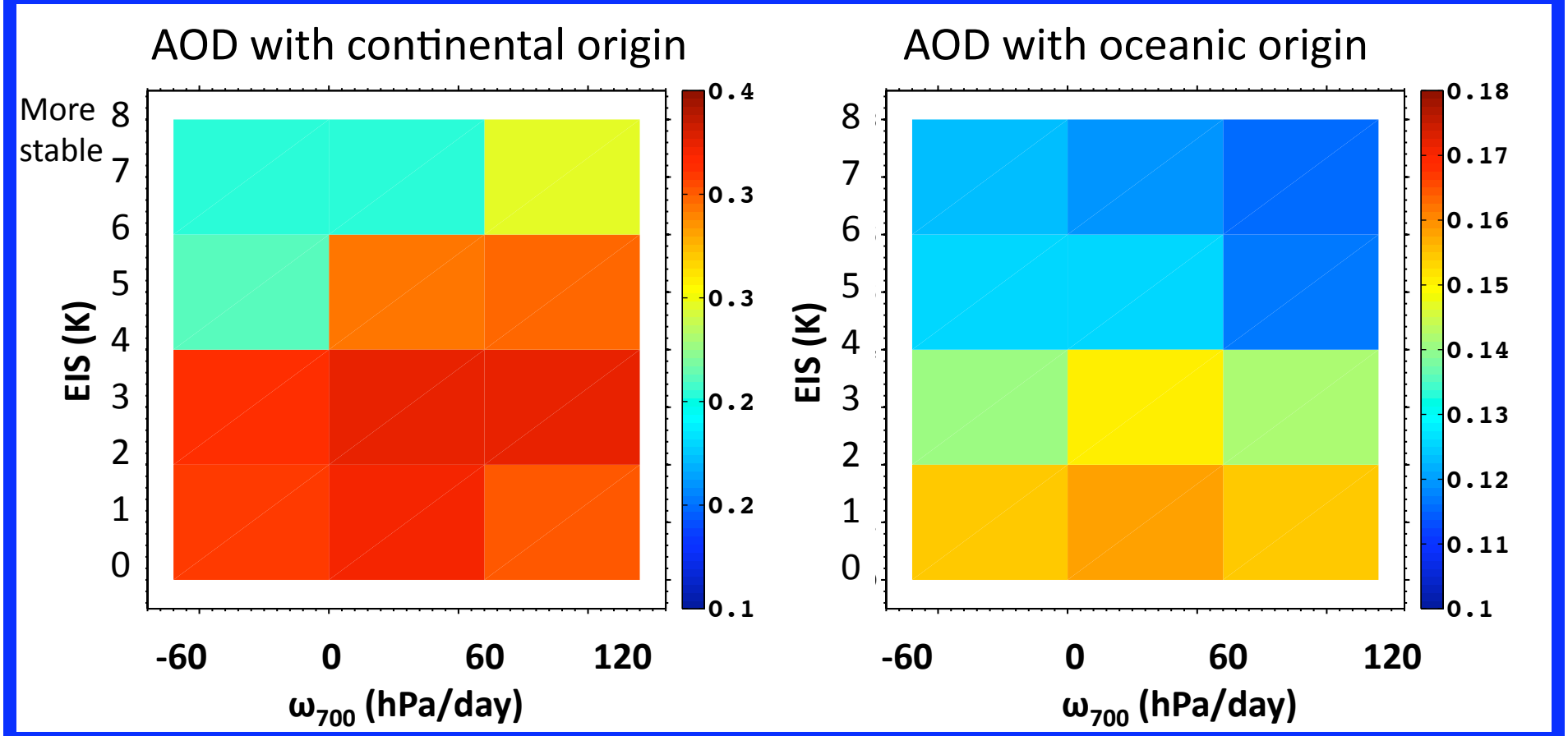




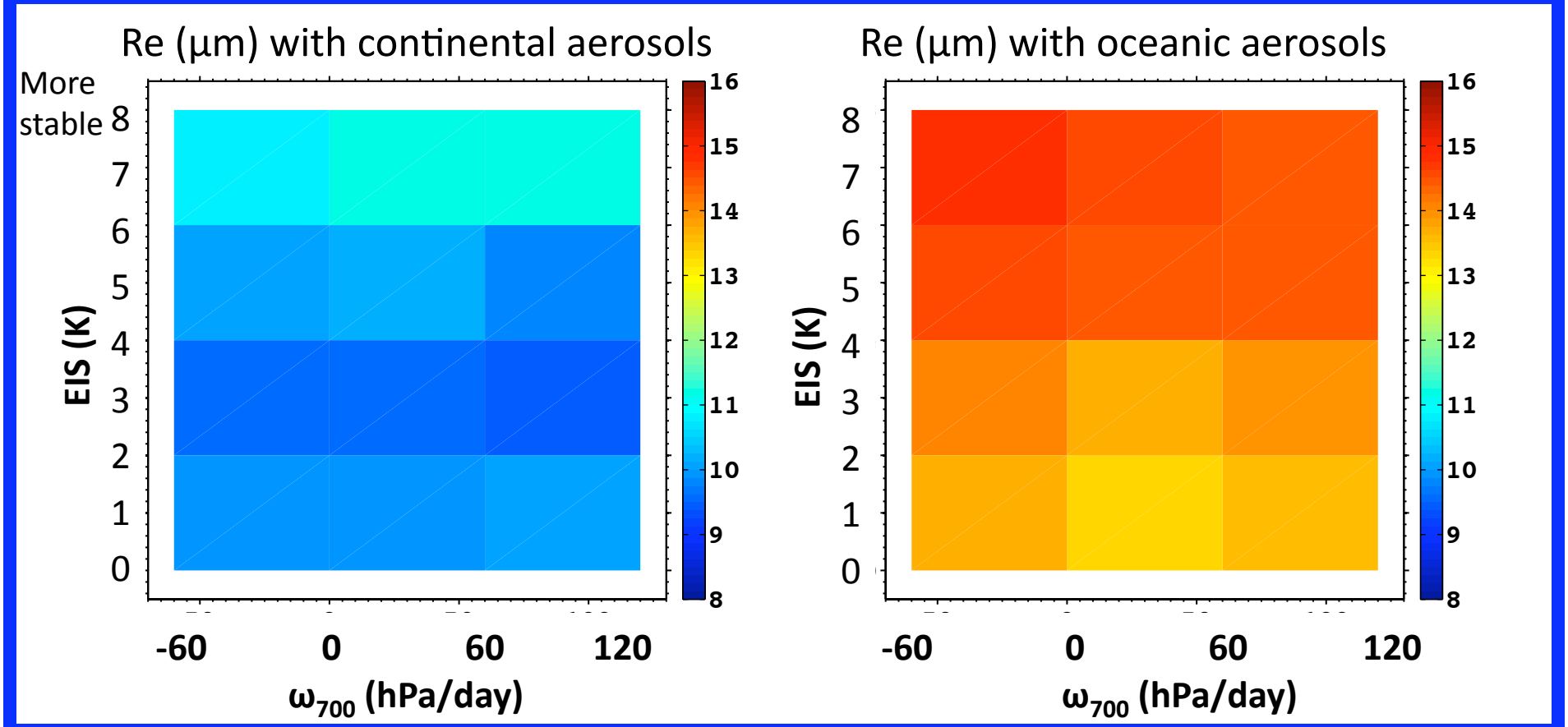
Stratify aerosol and cloud interactions by aerosol type, EIS and ω_{700}

- For a given 1 x 1 degree grid, if it contains single layer low clouds and both aerosol and cloud retrievals are available, then the grid is included in the analysis;
- Aerosol origin for this grid is determined based on the 72 hour back trajectory at 1500 m;
- Aerosol and cloud properties of this grid are put into an EIS/ω_{700} bin, based on the EIS and ω_{700} value of this grid. This is done separately for oceanic and continental aerosols;
- Averages and standard errors of aerosol optical depth (AOD) and cloud properties and TOA albedo are calculated for each EIS/ω_{700} bin.

EIS and ω_{700} stratified AOD: oceanic origin much smaller than continental origin



Cloud droplet effective radius (Re) associated with oceanic origin are larger than Re associated with continental origin

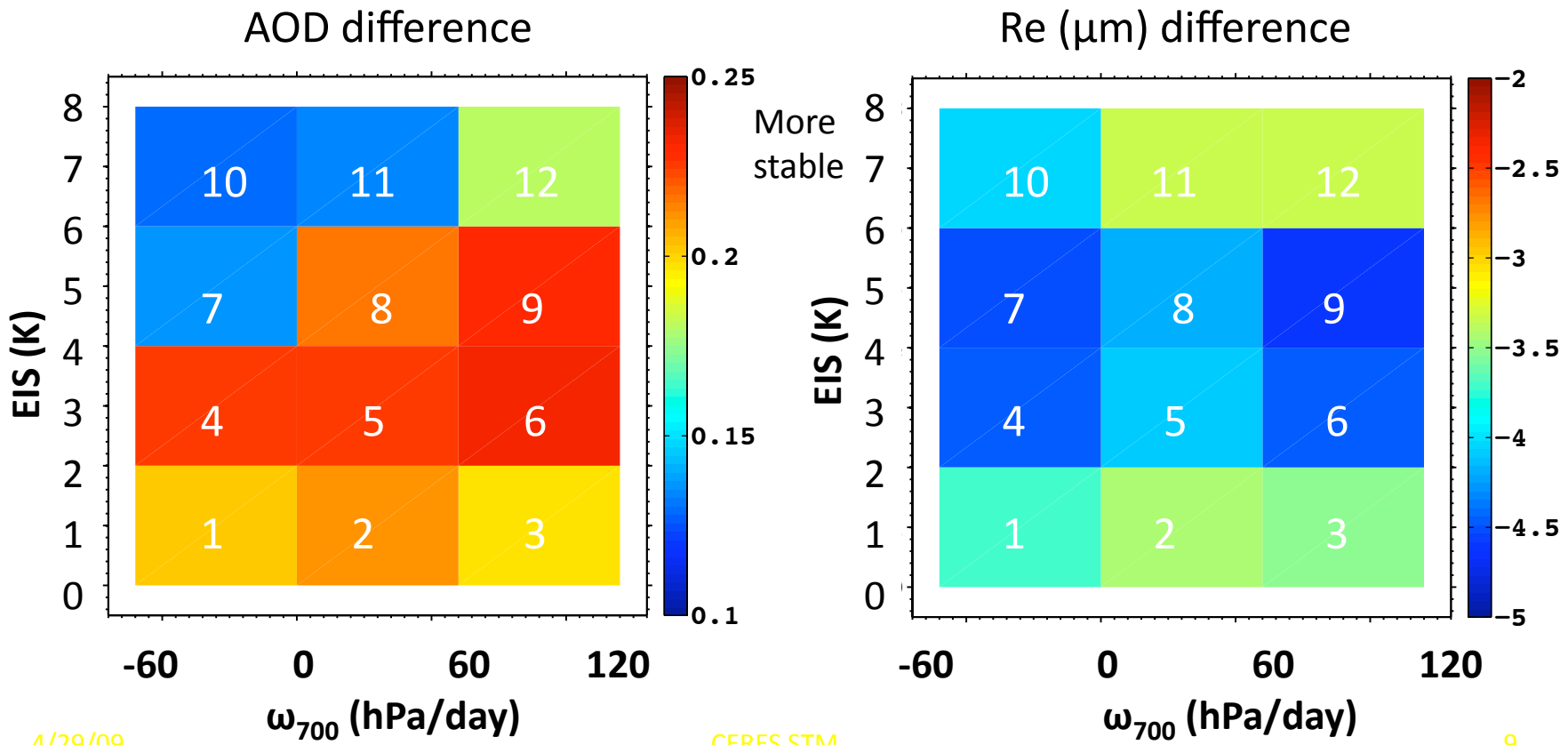


Differences of properties associated with aerosols of continental and oceanic origin: using AOD diagnostically

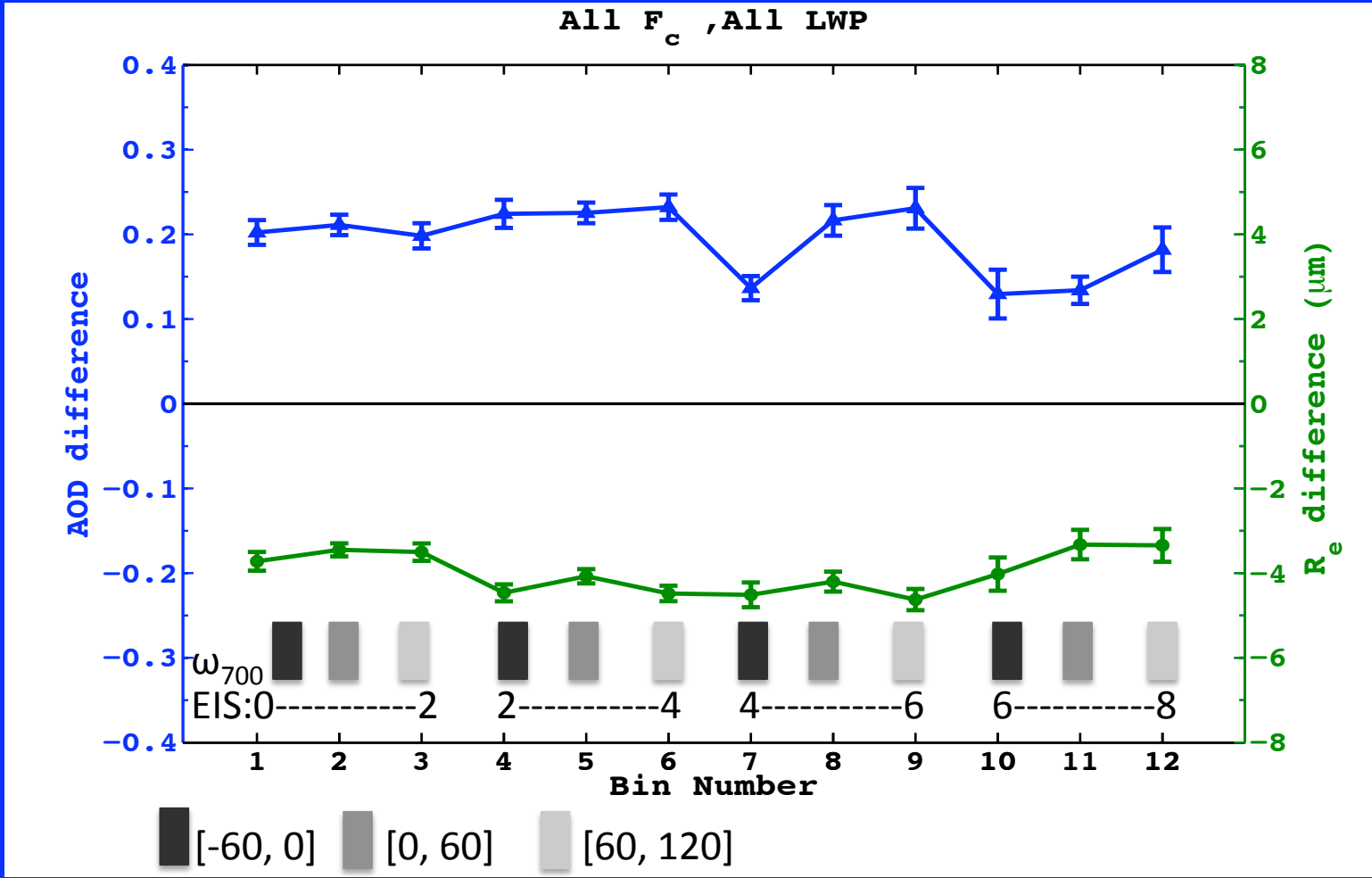
- Difference and the standard error of the difference are defined as:

$\Delta X_i = X_i^c - X_i^o$ $\qquad\qquad$ $\sigma_i^2 = (\sigma_i^c)^2 + (\sigma_i^o)^2$

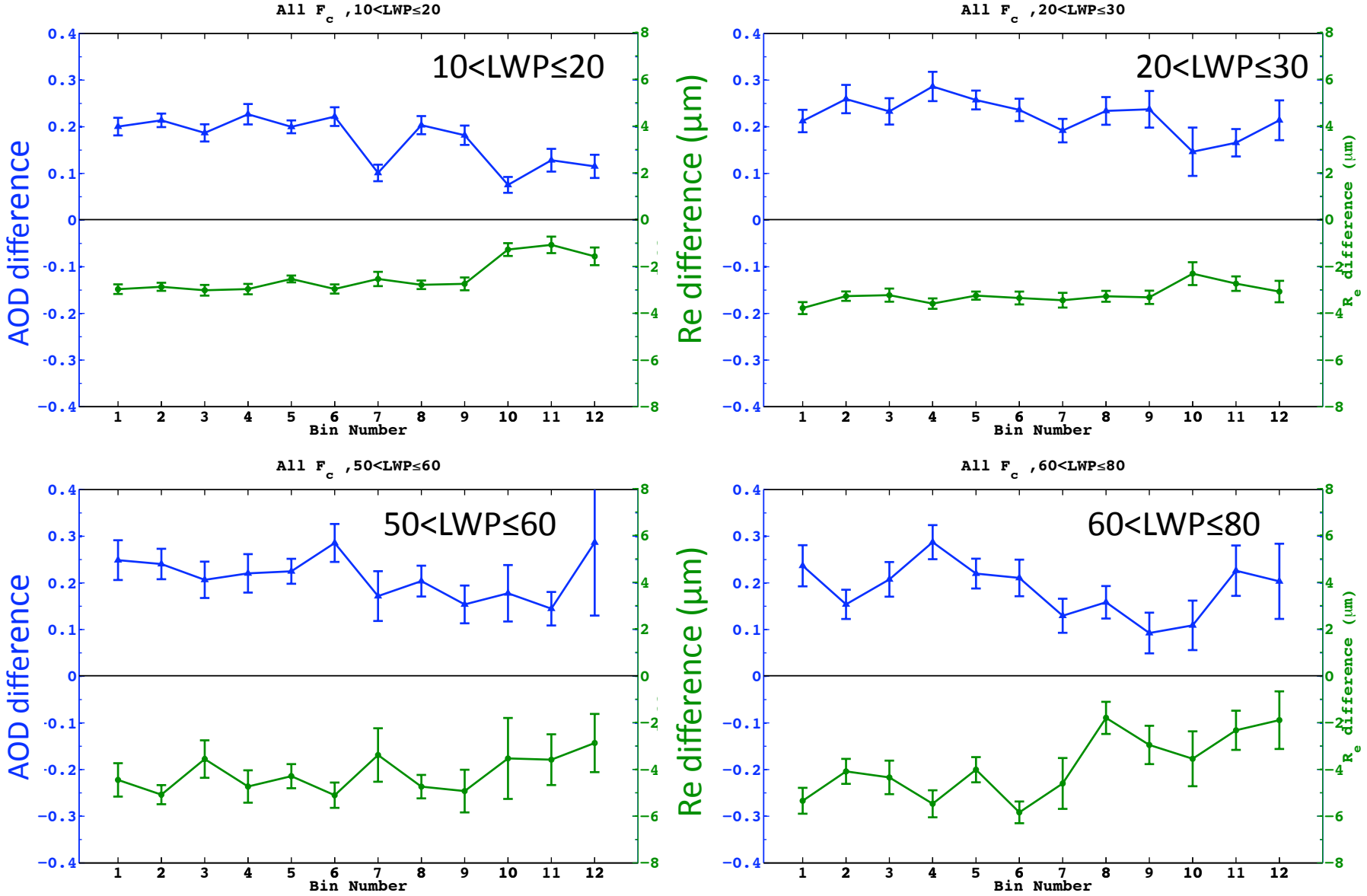
i is the bin number, c and o represent property associated with continental and oceanic aerosols



Re associated with aerosols of continental origin are smaller than those associated with oceanic origin across all EIS/ω_{700} bins



Under constant LWP: Cloud Re associated with continental aerosols are smaller than Re associated with oceanic aerosols

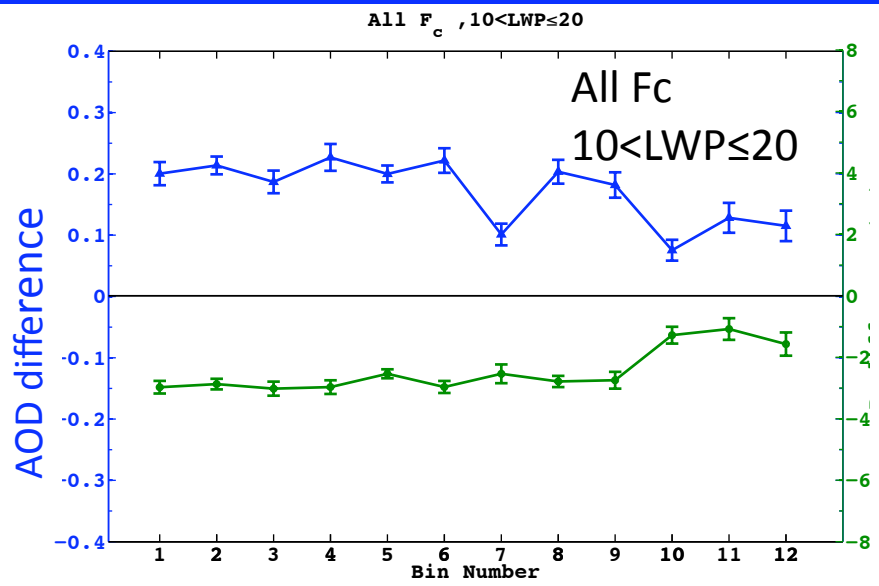


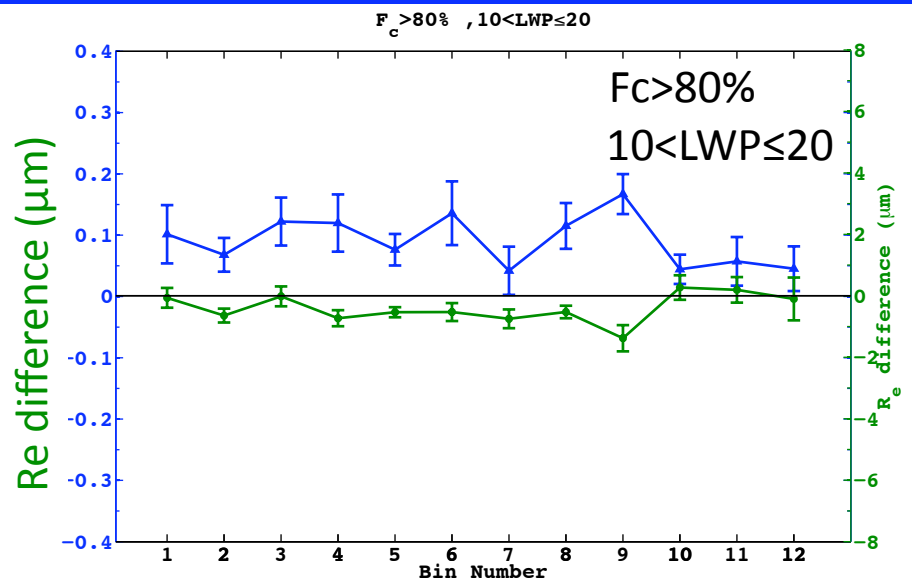
How much of the cloud Re differences are associated with the first indirect effect ?

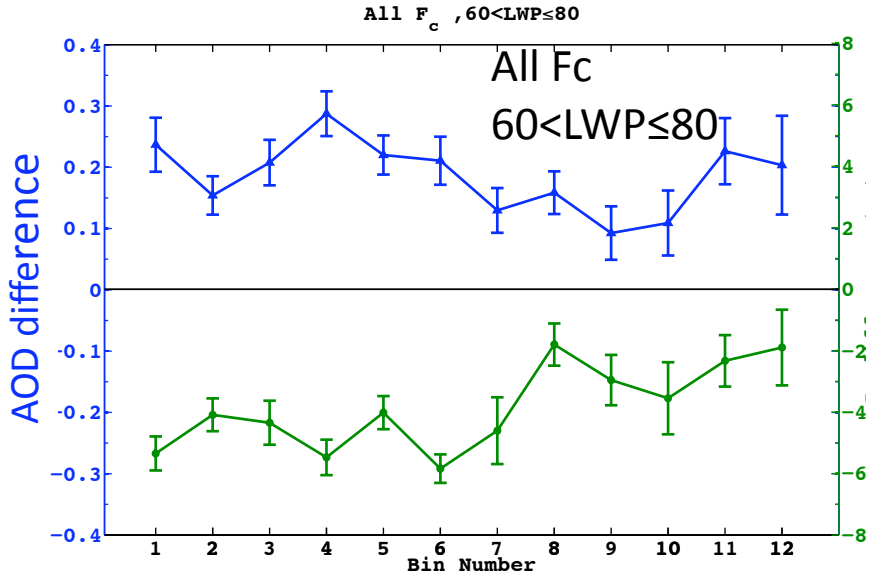
Under constant LWP: 30~40

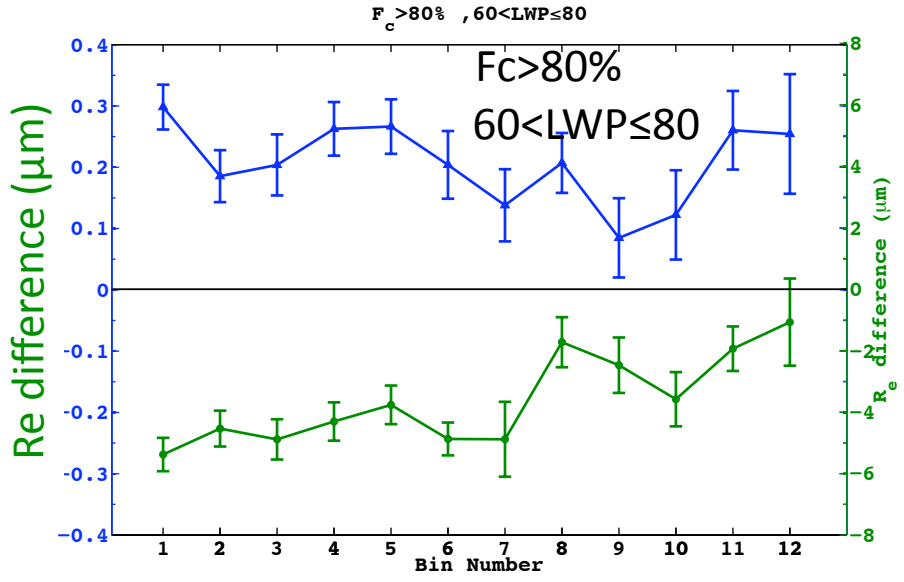
	Oceanic			Continental		
Fc range (%)	[30, 50]	[50, 80]	[80, 98]	[30, 50]	[50, 80]	[80, 98]
AOD	0.10	0.14	0.25	0.21	0.34	0.46
Angstrom	0.40	0.53	0.71	0.61	0.83	0.93
COD	2.0	2.4	3.8	2.7	3.5	4.7
Re (μm)	14.6	13.3	10.4	12.1	10.2	9.2
Fc (%)	39.8	63.8	89.7	39.1	66.8	91.6
LWP (g m-2)	34.8	34.9	35.1	34.5	34.5	34.7

Re differences are smaller for cloud cover>80% than for all cloud cover except for the highest LWP bin

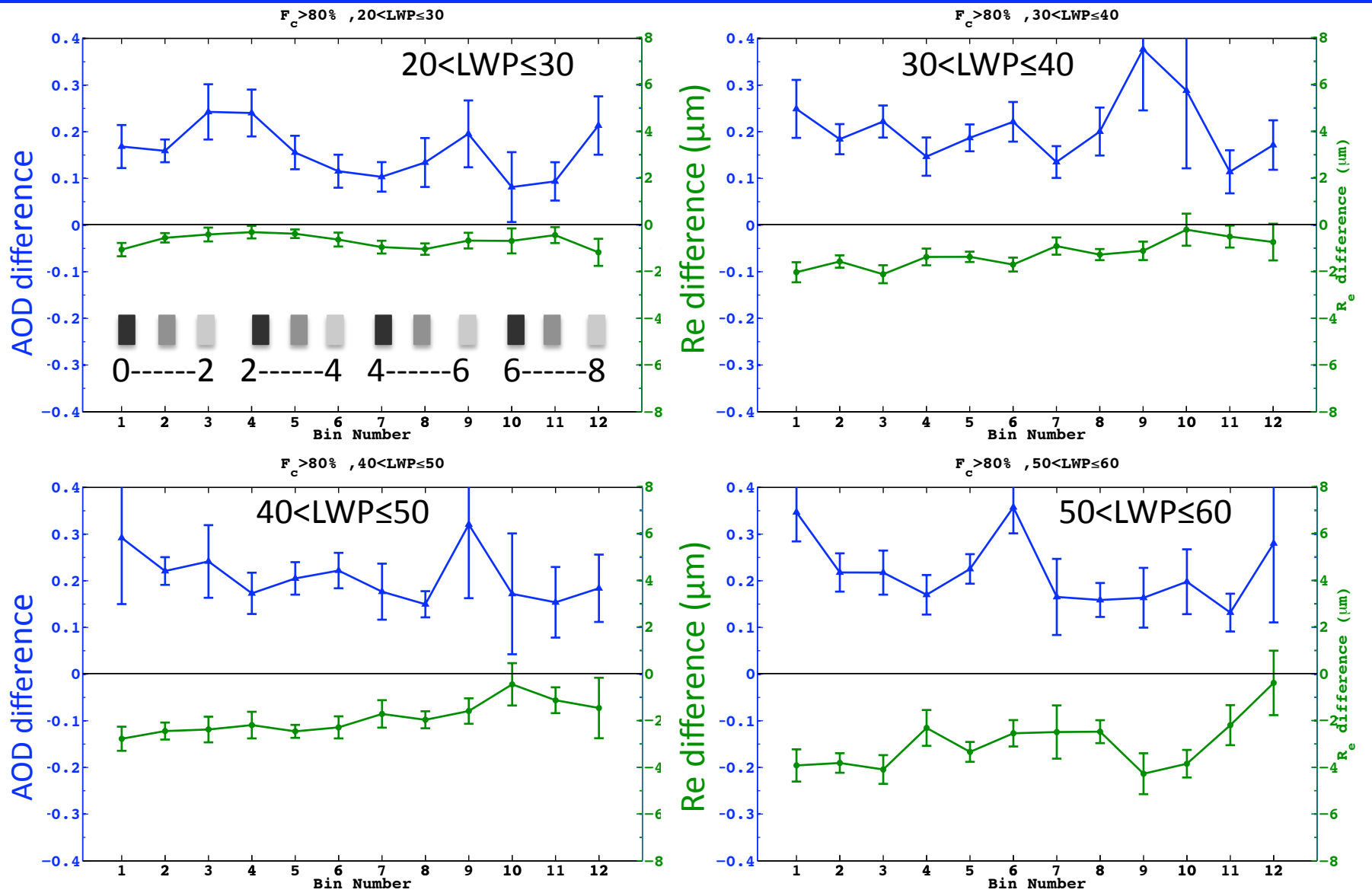




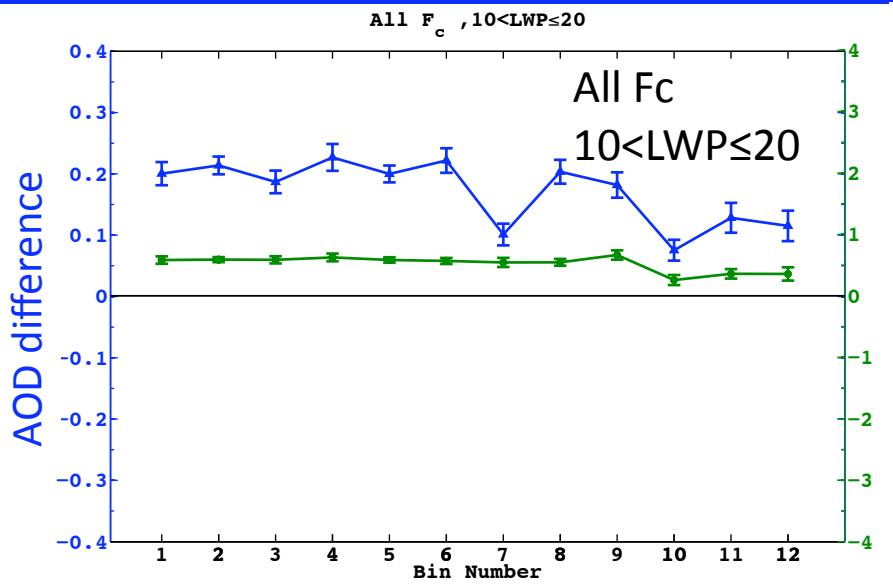


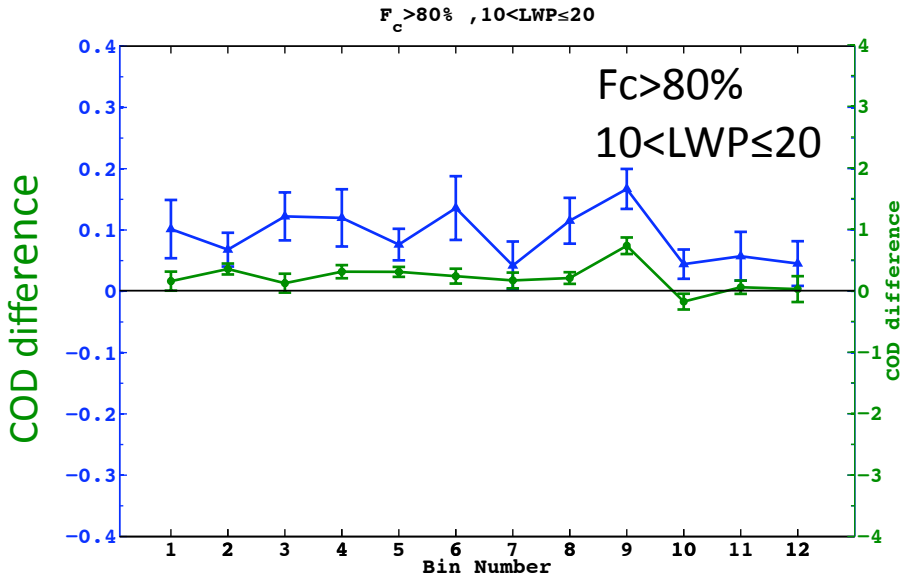


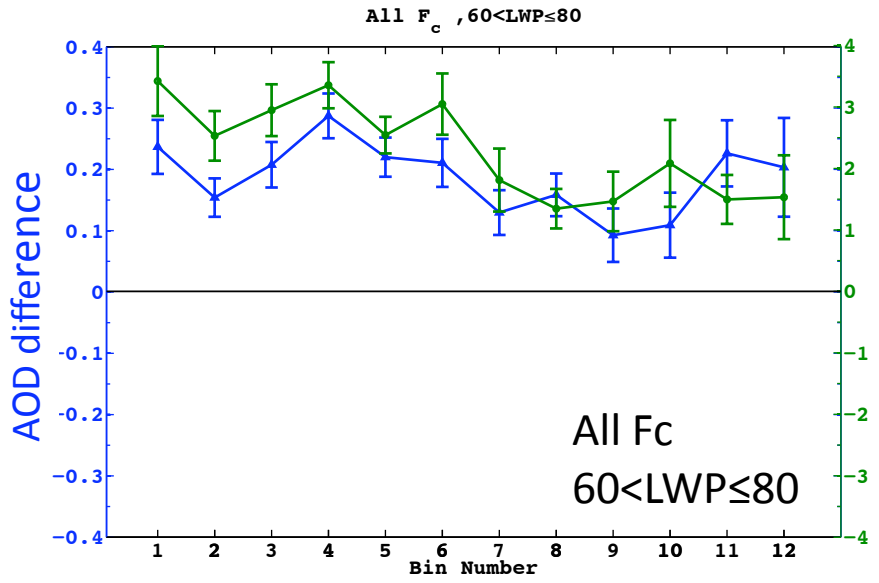
Re differences for cloud cover > 80% under constant LWP

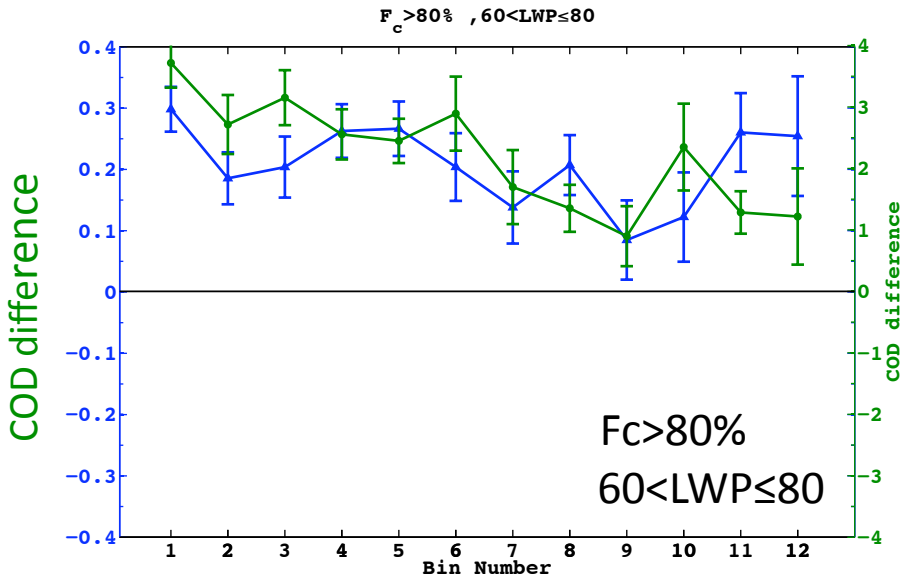


COD differences are smaller for cloud cover>80% than for all cloud cover except for the highest LWP bin

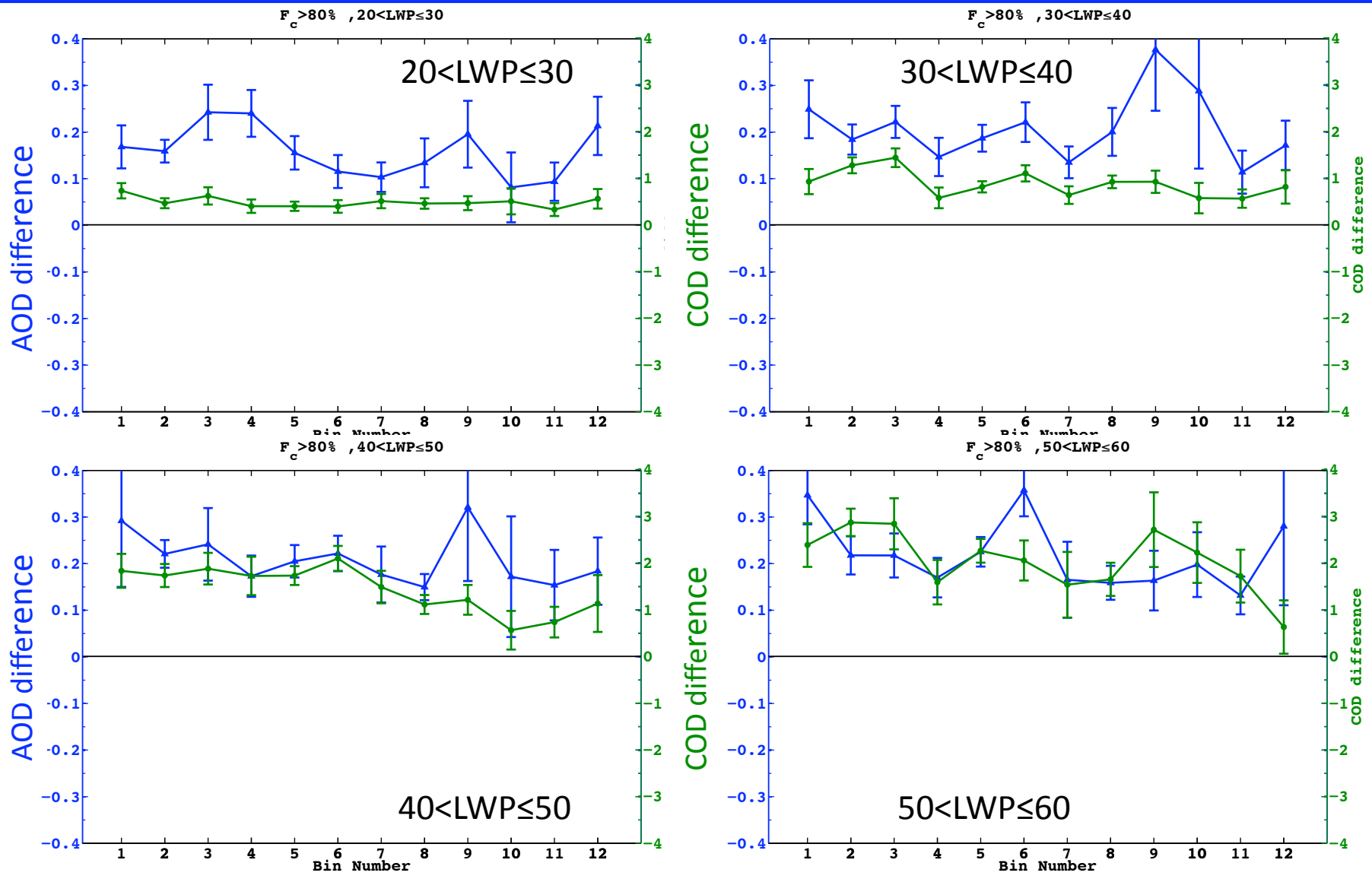




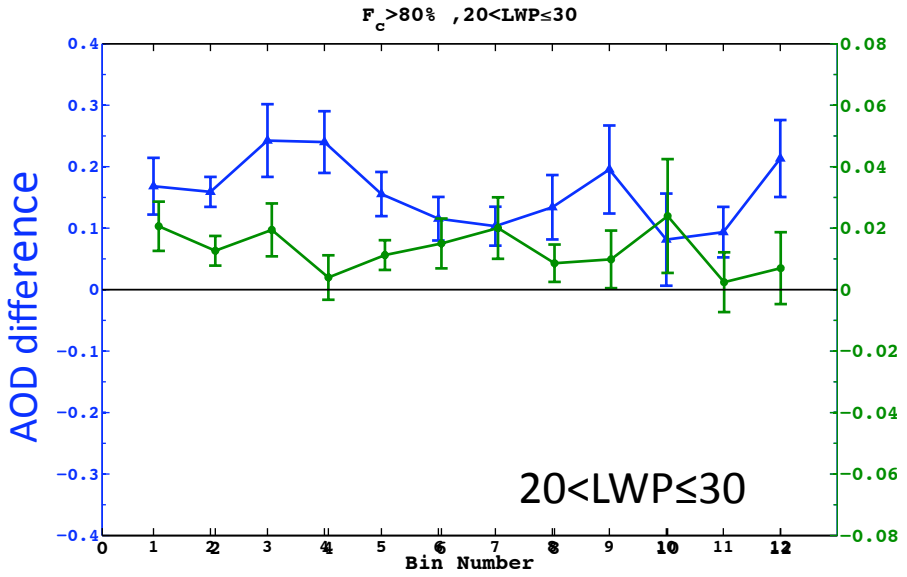


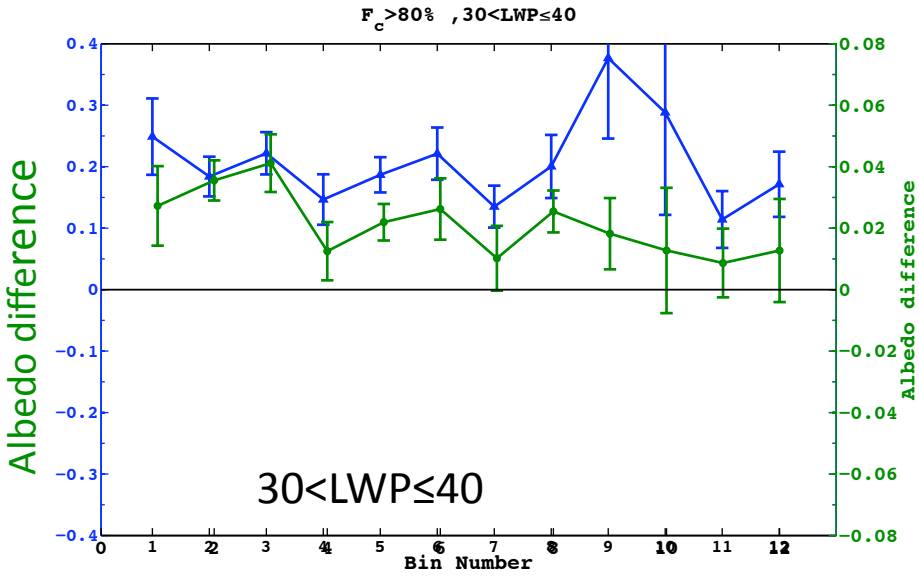


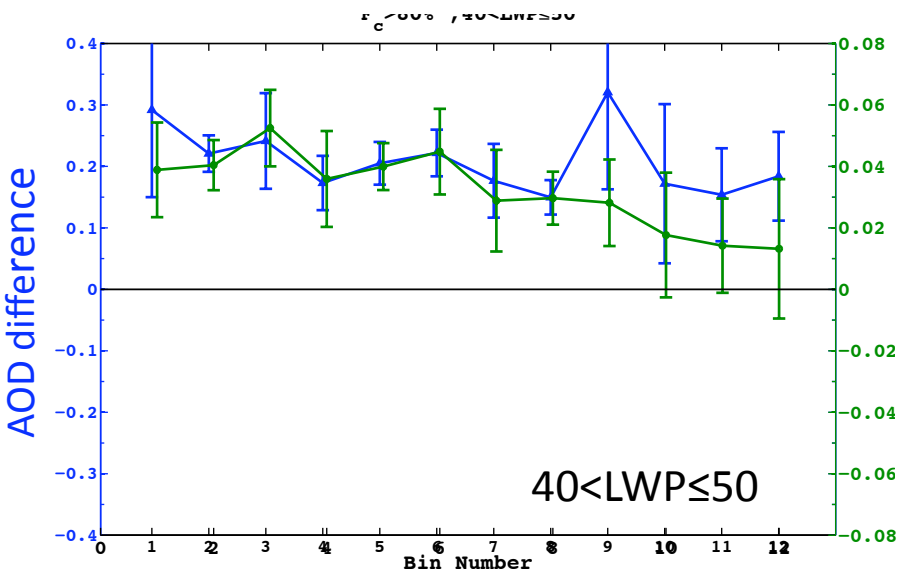
COD differences for cloud cover > 80% under constant LWP

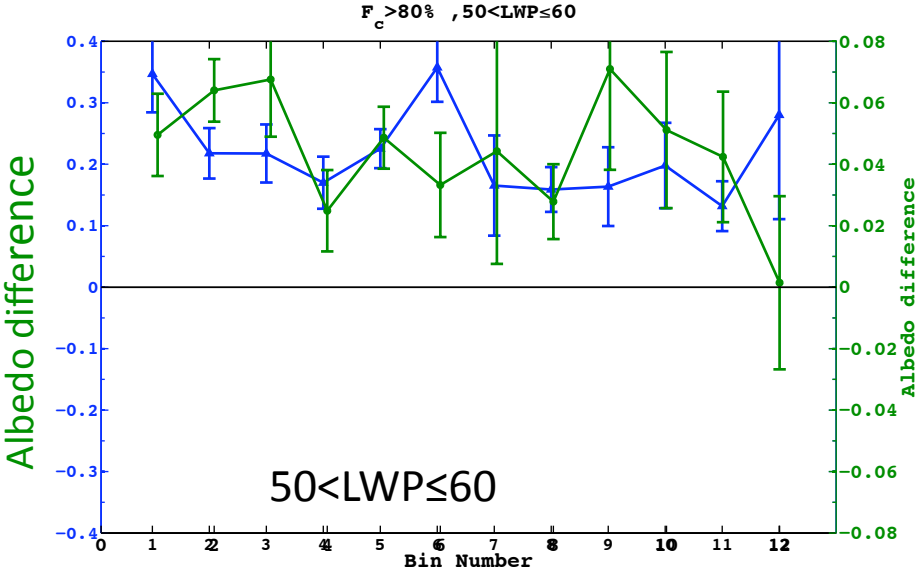


Albedo differences for cloud cover > 80% under constant LWP









Overall differences for all cloud fraction vs. for cloud cover > 80%

	All Fc	Fc > 80%
AOD	0.21±0.03	0.17±0.05
Re (μm)	-3.3±0.4	-1.3±0.4
COD	1.2±0.2	0.9±0.3
Fc (%)	20.7±2.90	1.8±0.9
Albedo	0.05±0.01	0.02±0.01

Conclusions

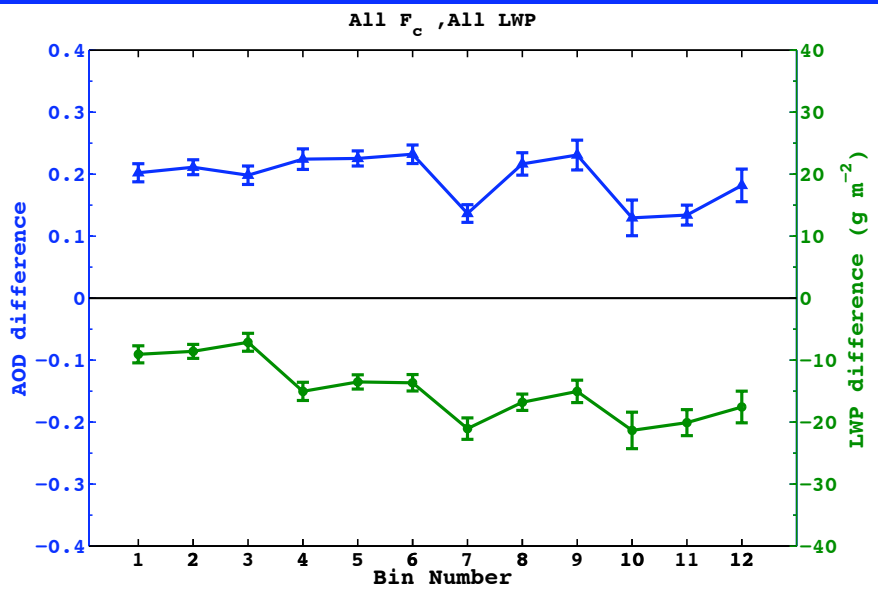
- We stratified cloud properties and TOA albedo associated with aerosols of continental and oceanic origin by EIS and ω_{700}. Under constant LWP:
  - Cloud droplet effective radius associated with aerosols of continental origin is smaller than oceanic origin; overall difference is about 3.3 μm
  - Cloud optical depth and TOA albedo associated with aerosols of continental origin are larger than oceanic origin; overall differences are about 1.2 and 0.05
- Furthermore, we constrain cloud cover > 80%
  - Cloud droplet effective radius associated with aerosols of continental origin is still smaller, but to a lesser extent; overall difference is about 1.3 μm
  - Cloud optical depth and TOA albedo associated with aerosols of continental origin are still larger, but to a lesser extent; overall differences are about 0.9 and 0.02

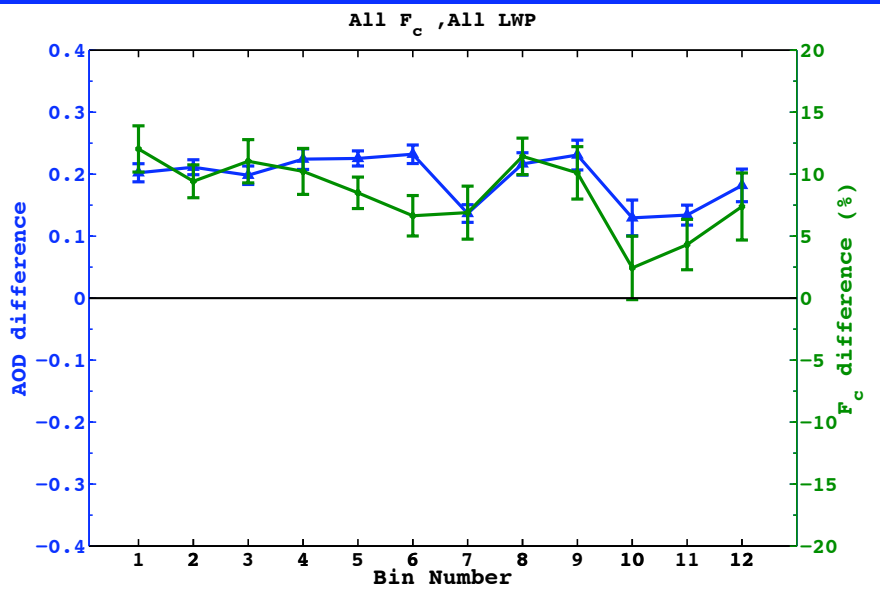
Backup slides

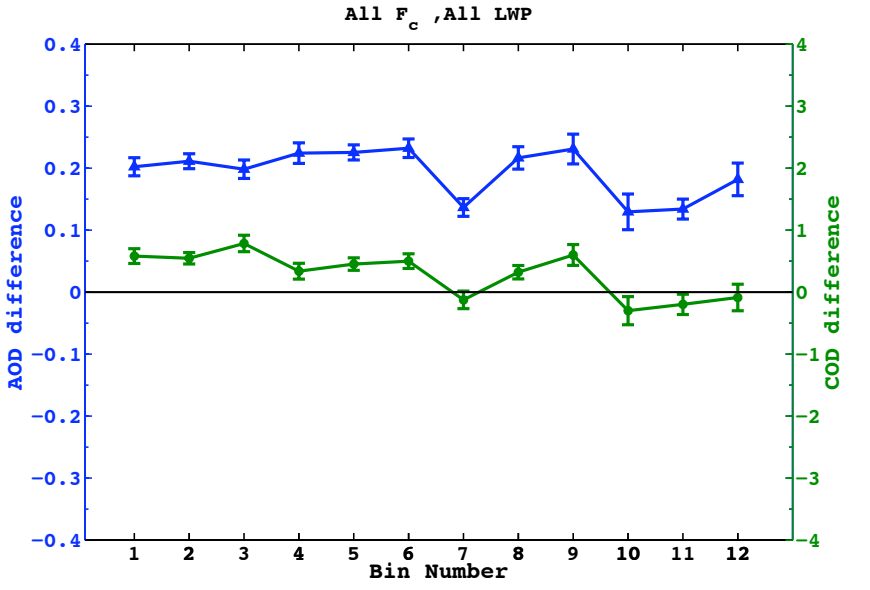
How much of the cloud Re differences are associated with the first indirect effect ?

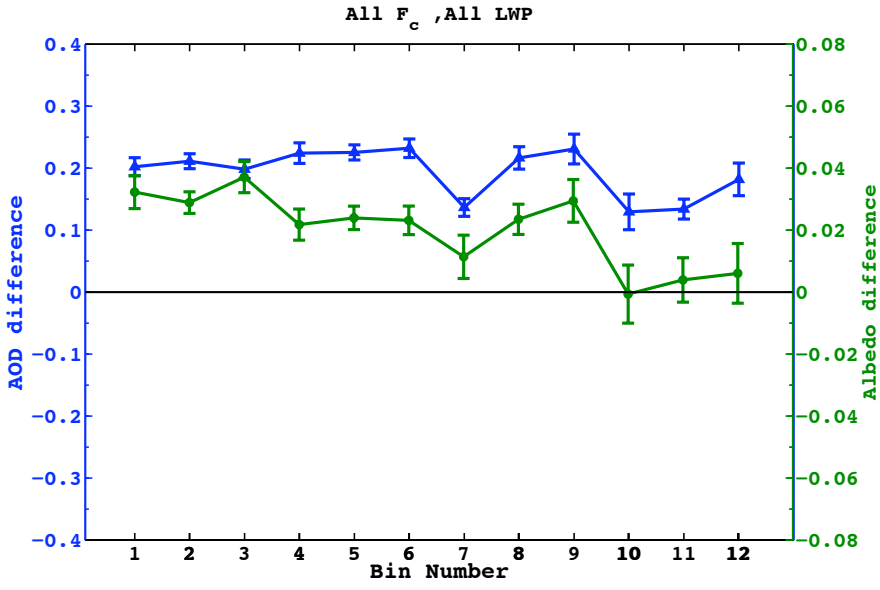
60<LWP<80	Oceanic		Continental	
	All Fc	Fc>80%	All Fc	Fc>80%
AOD	0.12	0.17	0.30	0.37
Angstrom	0.48	0.61	0.84	0.90
COD	3.7	4.9	6.0	7.0
Re (m)	16.6	15.2	12.7	11.6
Fc (%)	65.1	89.5	77.6	91.8
LWP (g m-2)	69.0	69.8	68.4	68.7

Clouds associated with continental aerosols have less LWP and more cloud fraction

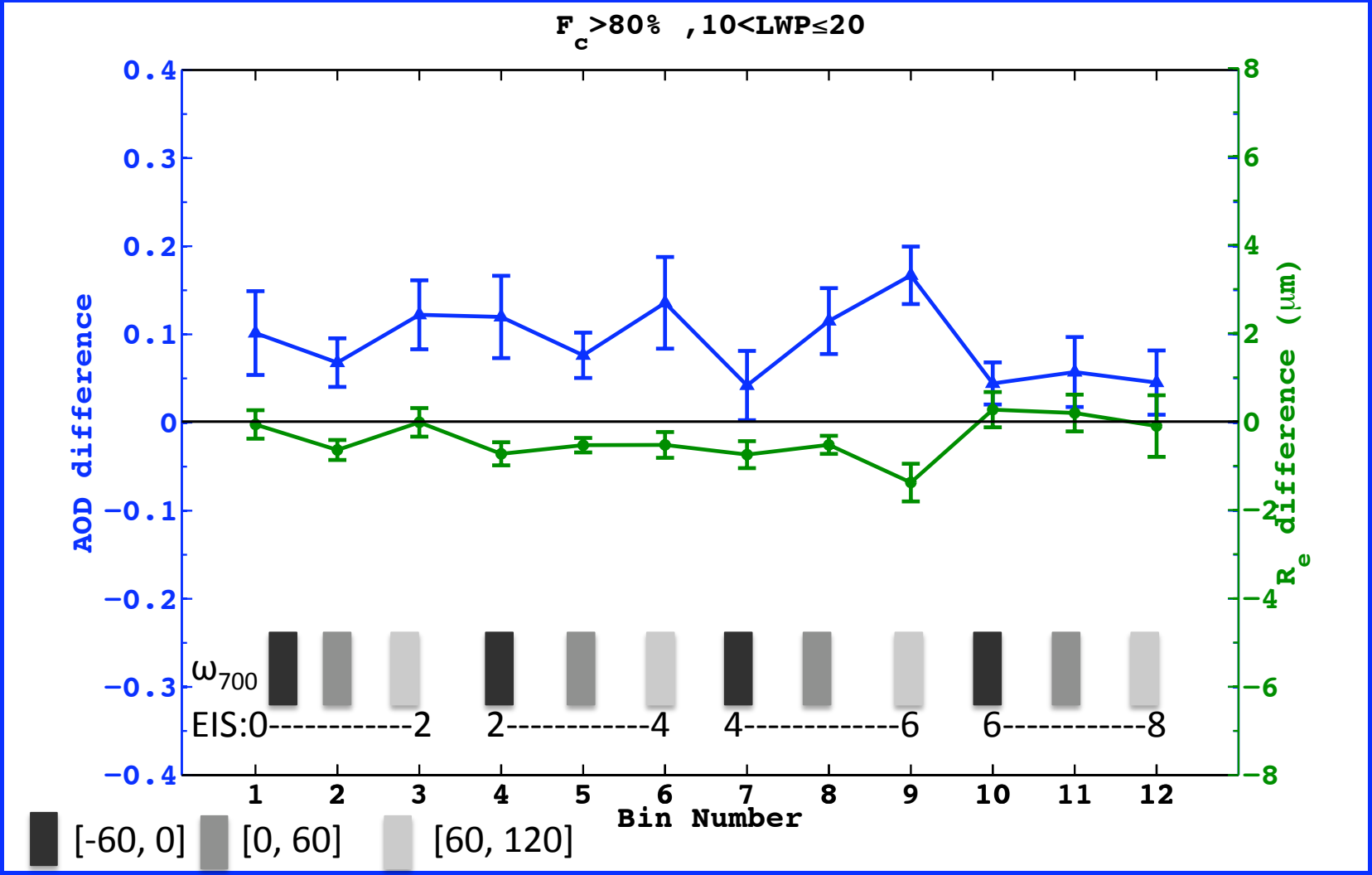




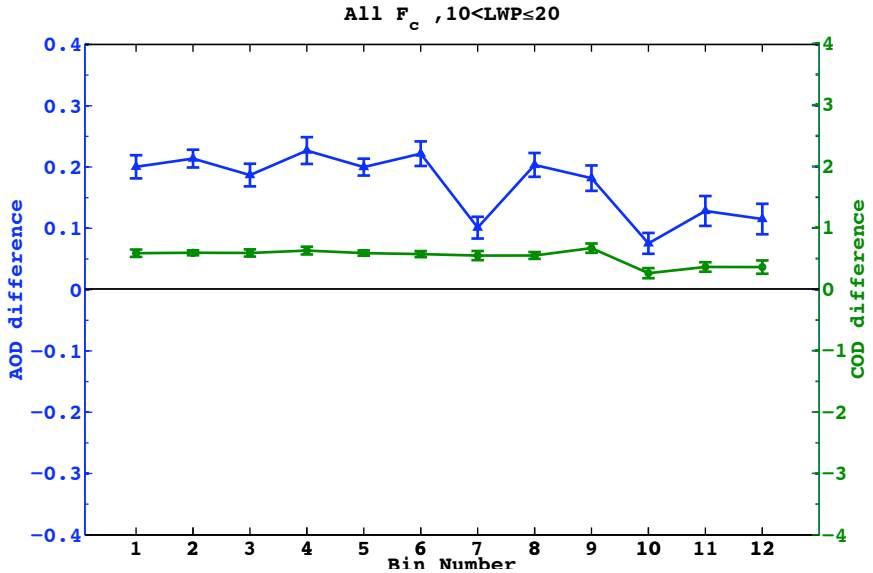


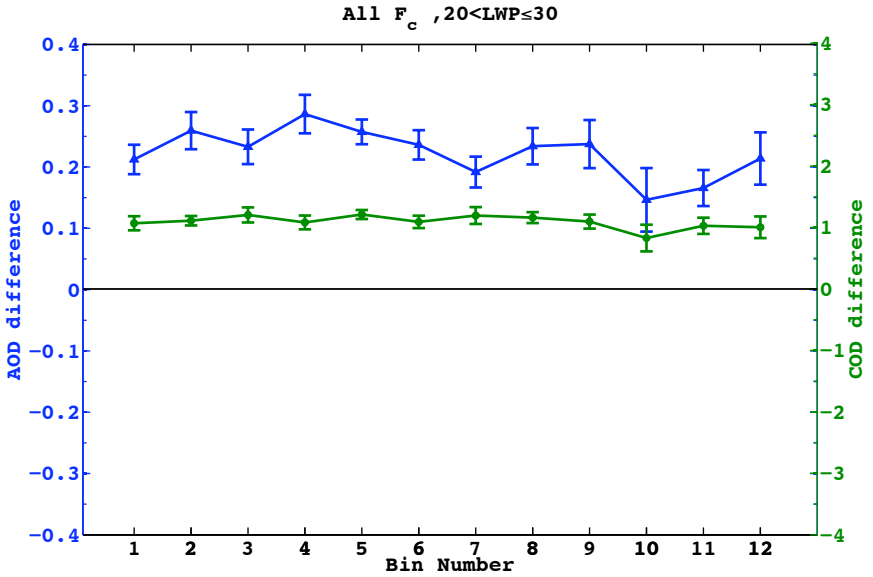


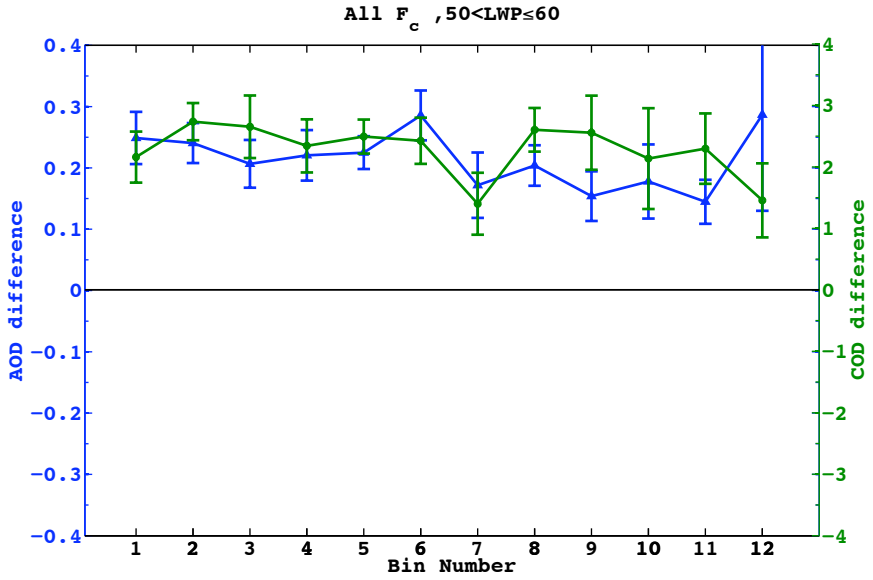
Re differences for cloud cover > 80% under constant LWP = [10, 20]

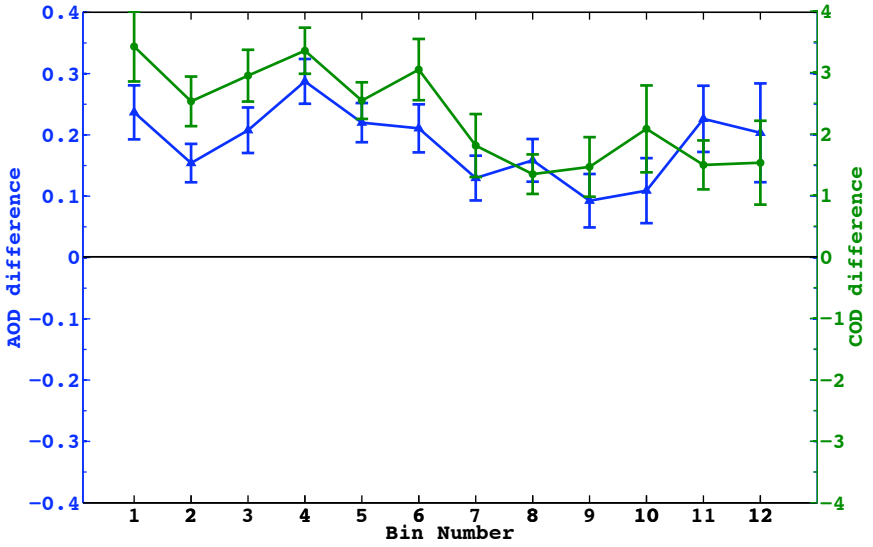


Under constant LWP: COD with continental origin aerosols are larger

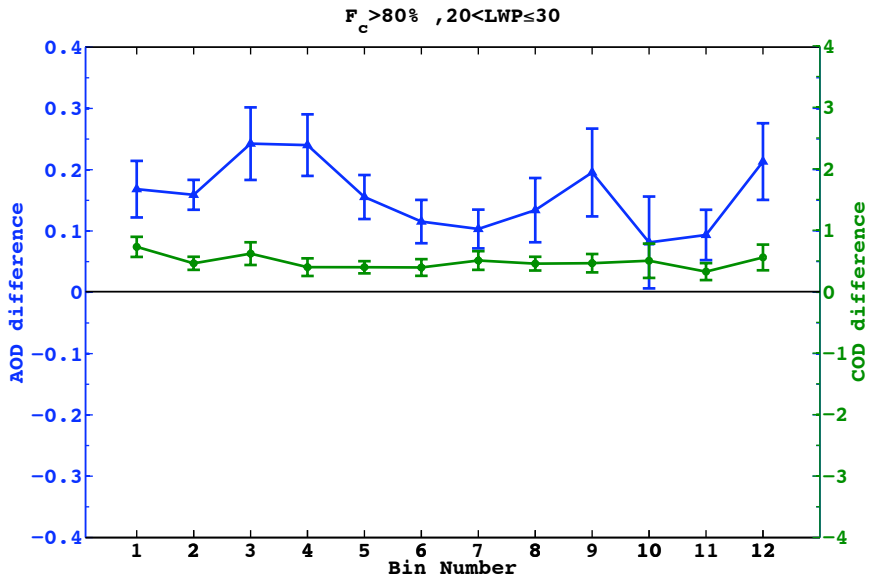


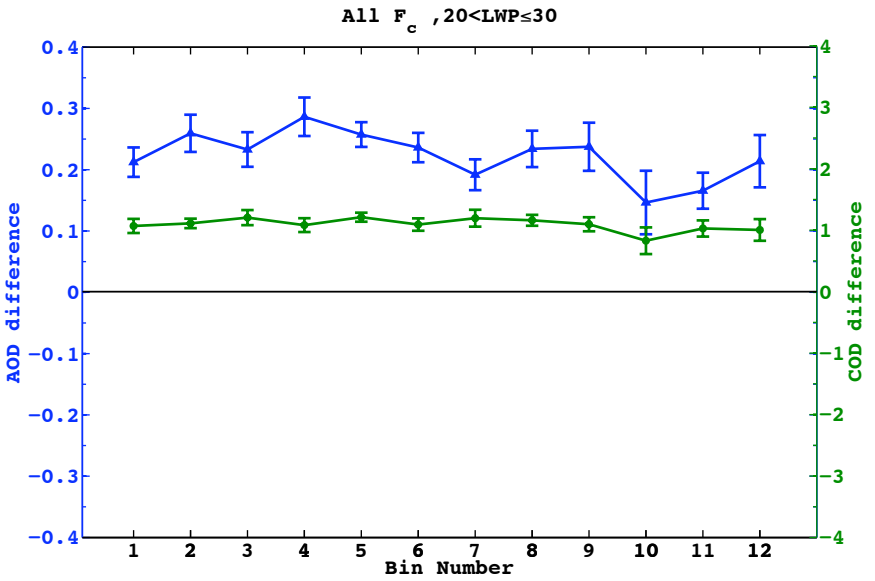


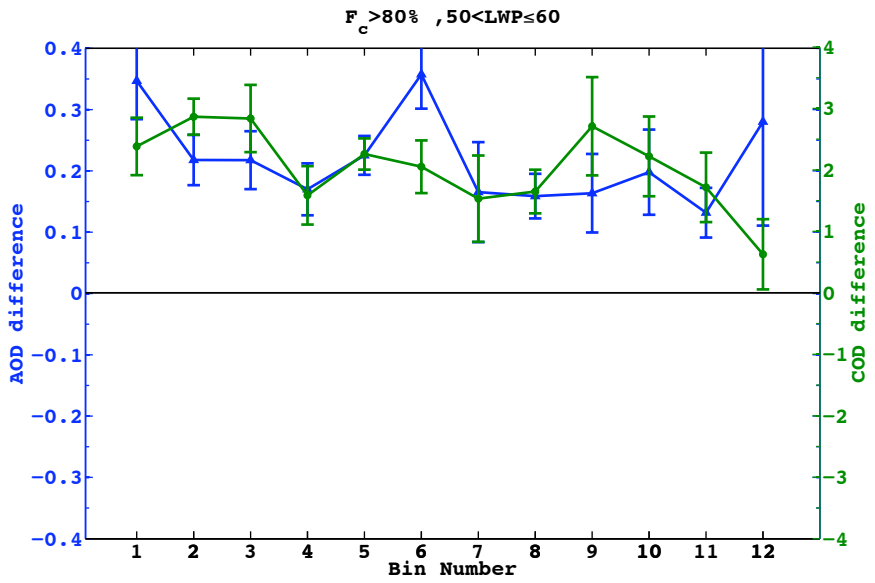


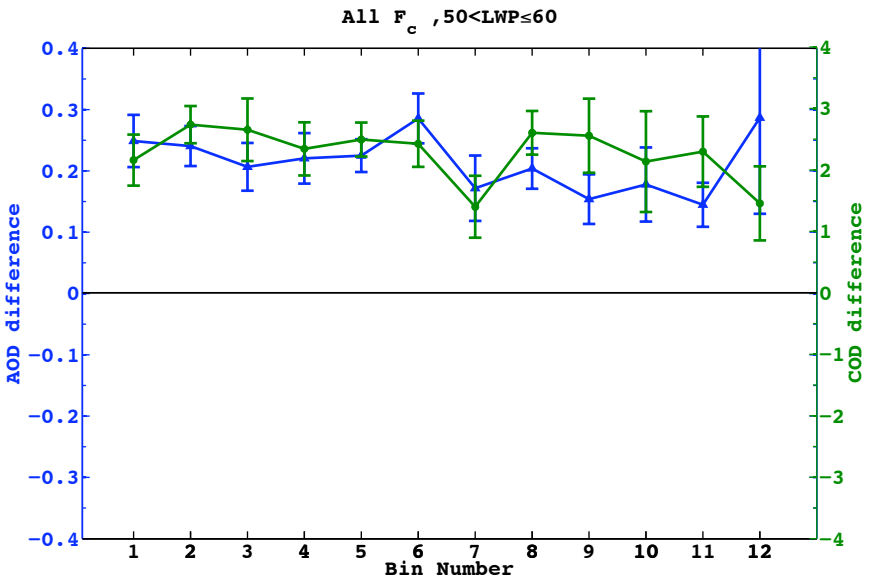


COD difference are smaller if constrained by cloud cover

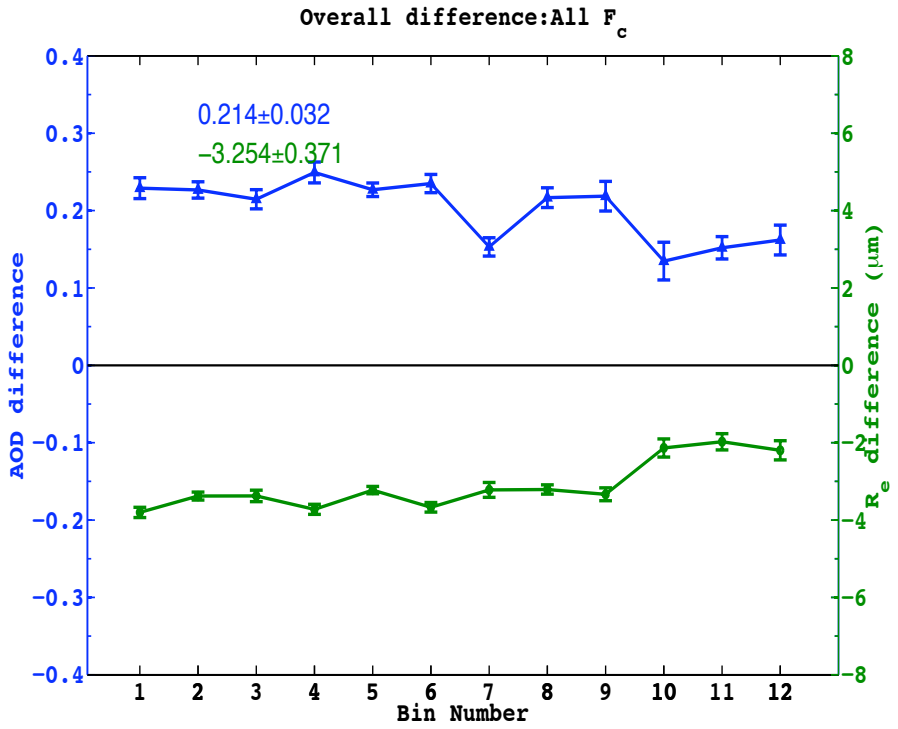


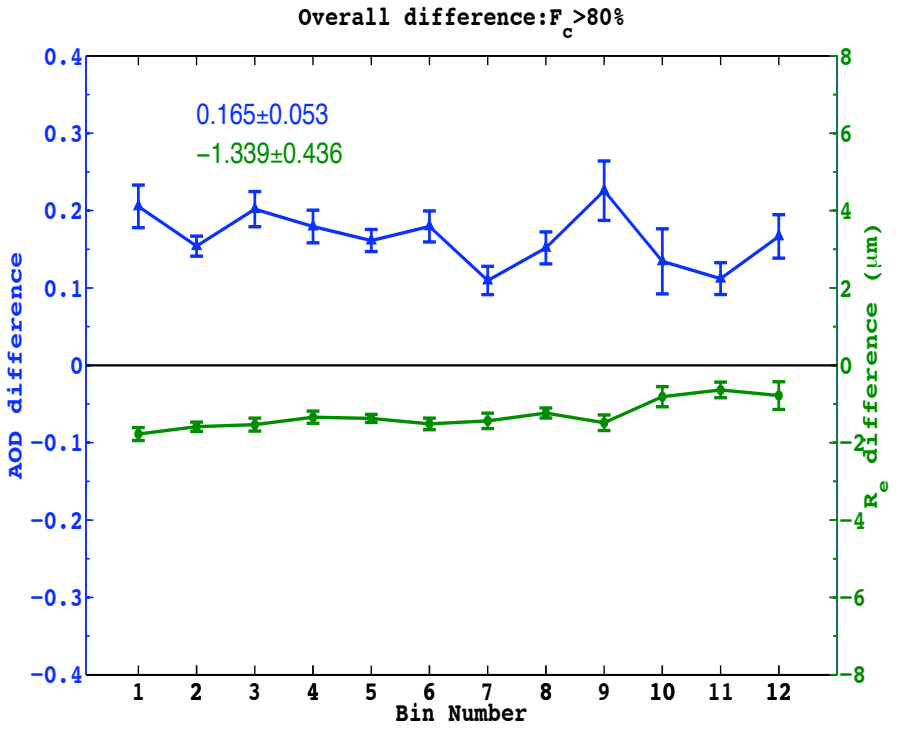




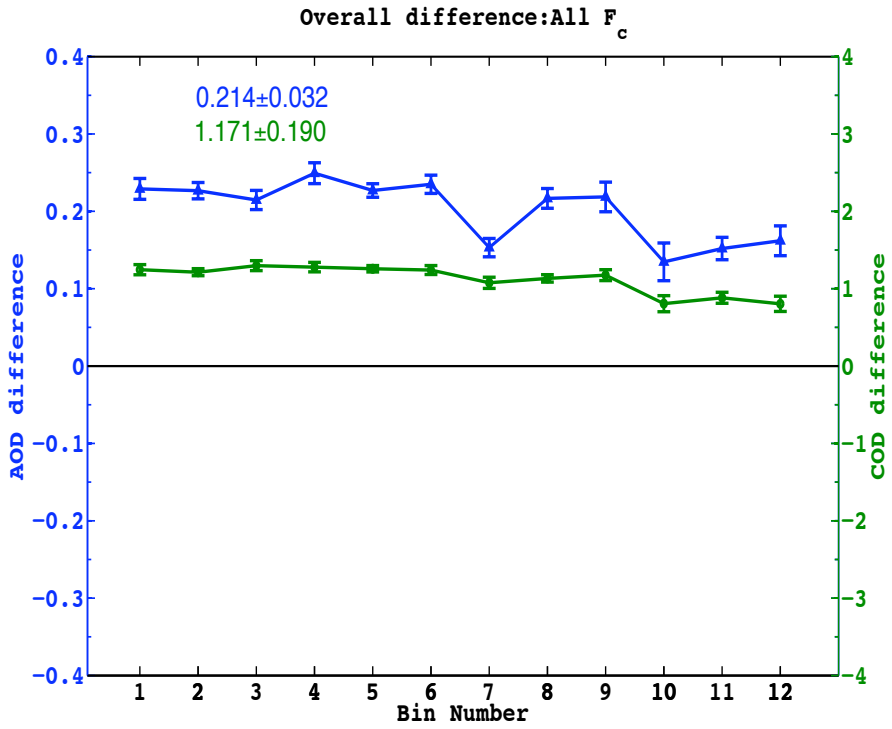


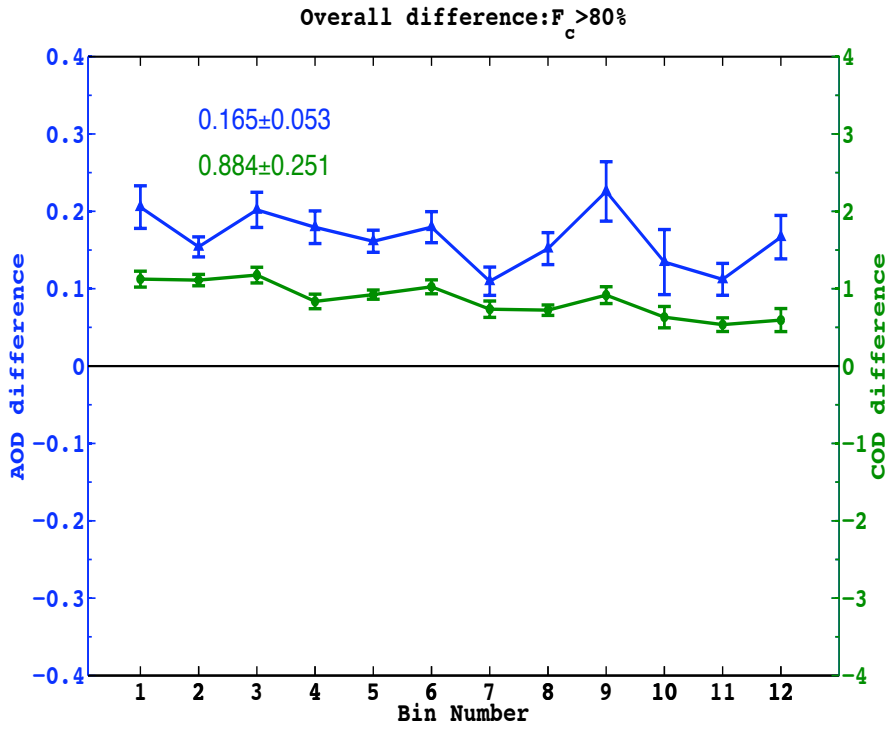
Overall Re difference is more than a factor of two smaller with constrained cloud fraction



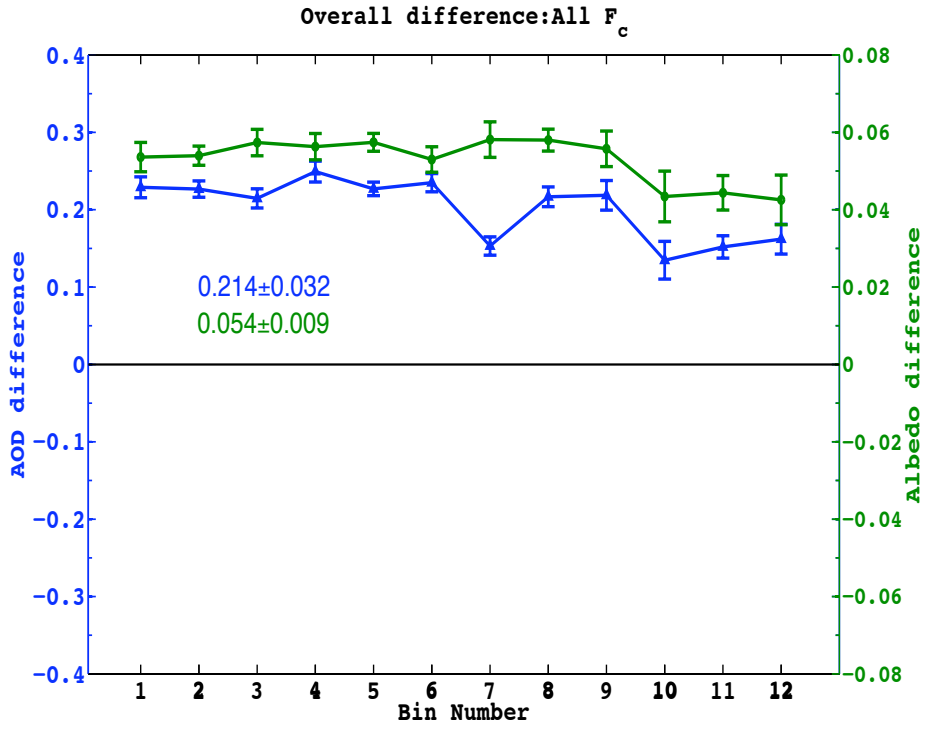


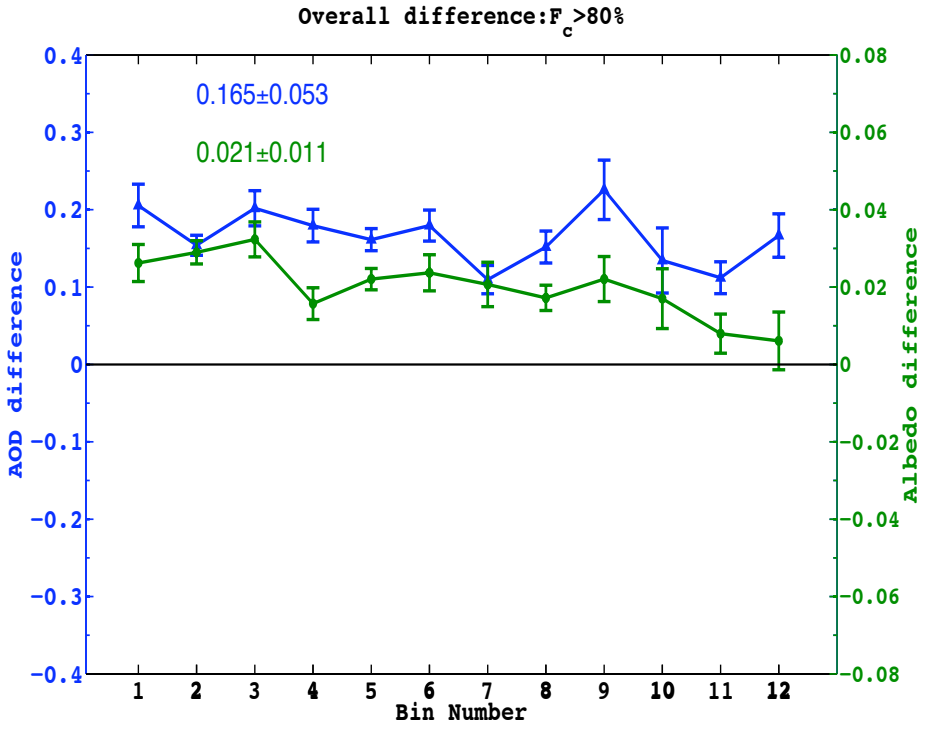
Overall COD difference is more than 25%smaller with constrained cloud fraction





Overall albedo difference is more than a factor of two smaller with constrained Fc





Overall cloud cover difference for cloud cover > 80%